W-74

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

March 1945 as
[redacted]eport 5C10

A METALLURGICAL INVESTIGATION OF A LARGE FORGED DISC OF 19-9 DL ALLOY

By J. W. Freeman, E. E. Reynolds, and A. E. White
University of Michigan

WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

[redacted]

A METALLURGICAL INVESTIGATION OF A LARGE FORGED DISC OF 19-9 DL ALLOY

By J. W. Freeman, E. E. Reynolds, and A. E. White

SUMMARY

During the course of a research investigation on the development of heat-resisting alloys for use in turbosupercharger and gas turbine applications it has been found that the properties of promising alloys are dependent to a large extent on the conditions of fabrication. Since the large size of certain gas turbine rotors introduced fabrication procedures for which information was not available, a research program is in progress to ascertain their influence on the properties of the better alloys.

An investigation of the properties of a 20-inch diameter by $3\,^1/_4$-inch disc of 19-9 DL alloy in the as-forged and stress-relieved condition gave the following principal results:

A. Offset Yield Strengths

	(lb/sq in.)
0.02% offset yield strength at room temperature	39,275
0.2% offset yield strength at:	
room temperature	54,700
900° F	38,000
1200° F	37,900
1350° F	31,000

B. Rupture-Test Characteristics

	Stress to cause rupture in indicated time periods (lb/sq in.)		
	(10 hr)	(100 hr)	(1000 hr)
1200° F rupture strength	46,000	40,000	34,000
1350° F rupture strength	28,000	23,000	15,500

The elongation and reduction of area of the fractured rupture-test specimens were high.

C. Total Deformation Characteristics Under Stress

	Stress for total deformation in indicated time periods (lb/sq in.)		
	(10 hr)	(100 hr)	(1000 hr)
0.1 percent total deformation at 1200° F	16,000	14,000	12,000
0.2 percent total deformation at 1200° F	24,000	21,000	17,000
0.5 percent total deformation at 1200° F	29,000	26,000	23,500
1.0 percent total deformation at 1200° F	32,500	29,000	26,000
Transition to third-stage creep at 1200° F	------	39,000	33,000
0.1 percent total deformation at 1350° F	11,000	8,500	5,000
0.2 percent total deformation at 1350° F	16,000	12,000	7,500
0.5 percent total deformation at 1350° F	21,500	16,000	11,000
1.0 percent total deformation at 1350° F	24,000	18,500	12,500
Transition to third-stage creep at 1350° F	------	------	8,000

D. Uniformity

The properties of the disc were very uniform for a forging of the size under consideration.

The strength values at 1200° F for time periods less than 1000 hours and at high rates of deformation were lower than have been obtained for 19-9 DL in other forms. For time periods of 1000 hours, however, it was about equal to hot-cold-worked materials. In this respect it was quite similar to the solution-treated condition. Plain as-rolled bar stock has had equivalent longer time strengths although the tensile properties and rupture strengths for short-time periods have been slightly higher.

The properties at 1350° F were low, especially on the basis of stresses required to cause total deformations of 1 percent or less in time periods up to 2000 hours. Instability and the early onset of third-stage creep were apparently responsible for the low load-carrying ability at this temperature.

Improvement of yield strength and sustained load-carrying ability of large discs of 19-9 DL alloy for time periods up to 1000 hours can only be accomplished by cold working the metal. A commercial process of cold working discs of the size considered in this investigation has recently been developed.

INTRODUCTION

The development of successful gas turbines for use in power plants for aircraft and other types of transportation units is of major importance to the war effort. It is dependent to a considerable extent on alloys being available which can withstand the high temperatures and stresses encountered in their operation. Extensive research work, consequently, is in progress with the object of providing suitable alloys for the high-temperature service of the wheels and buckets of the gas turbine rotors.

Several alloys have been developed which have promise of being suitable for many designs. It was known, however, that their properties varied to a considerable extent with manufacturing procedures, especially the amount of cold work imparted and heat treatments used. The amount of cold work and the types of heat treatment may be limited by the large size of the gas turbine rotors. Since data were lacking regarding the possible level of properties obtainable in the large rotor forging, an investigation of several new alloys in this form was undertaken.

The results obtained from an investigation of a large disc of 19-9 DL alloy, one of the better new alloys, in the as-forged and stress-relieved condition are the subject of this report. Design data were obtained for the

W-74

alloy in this form. Available data on experimental bar stock and other fabricated conditions were considered of doubtful value in view of the known variations in properties resulting from differences in fabrication procedure. The results also were expected to be useful in appraising the relationship between the properties of experimental bar stock and final products, as well as providing fundamental metallurgical knowledge.

The work was carried out as part of two correlated programs of research on alloys for gas turbine applications in progress in this country. The National Advisory Committee for Aeronautics is sponsoring work directed toward the development of improved high-temperature alloys for gas turbines used in aircraft power plants. A concurrent program under the auspices of the War Metallurgy Committee of the National Defense Research Committee, Office of Scientific Research and Development, has been directed to the development of alloys for gas turbine applications in general. A high degree of cooperation has existed between the two programs and between interested alloy producers. The work covered in this report is an example of this cooperation.

The 19-9 DL steel disc was produced by the Universal-Cyclops Steel Corporation as an aid in developing the alloy. The investigation of the disc was conducted jointly at the Department of Engineering Research of the University of Michigan and at Battelle Memorial Institute. This report has been prepared by the NACA since the investigation was limited to room temperature and 1200° and 1350° F properties, the temperature range covered in most of its activities.

EXPERIMENTAL PROCEDURE

The investigation was designed to provide three types of information: (1) the physical properties, both at room temperature and at 1200° and 1350° F, which can be expected in large forgings of the 19-9 DL analysis; (2) the variation in properties which might be present in various locations in such large forgings; and (3) the change in properties resulting from exposure to elevated temperatures under stress for prolonged time periods.

Complete physical-property data were obtained for the purpose of providing a basis for design in the use of large forgings of 19-9 DL steel. Short-time tensile properties, rupture-test characteristics up to 2000 hours at 1200° and 1350° F, and curves of stress versus time for total deformations of 0.1, 0.2, 0.5, and 1 percent at 1200° and 1350° F were determined. The time-deformation data were obtained from creep and rupture-test time-elongation curves.

The uniformity of the disc material was checked by means of a hardness survey and by tensile and rupture tests on coupons from representative locations throughout the disc. Hardness, tensile, and impact tests and metallographic examinations of completed test specimens were used to estimate the stability of the material after prolonged exposure to temperature and stress.

The NACA and the NDRC cooperated in conducting the testing program. Tensile tests at room temperature and at 1200° and 1350° F, rupture tests at 1200° and 1350° F, and creep tests at 1200° F and part of the creep tests at 1350° F were run at the University of Michigan under the sponsorship of the NACA. The Battelle Memorial Institute conducted tensile tests at room temperature and 900° F, constant stress-tension tests at 800° and 900° F, and part of the creep tests at 1350° F for the NDRC.

The details of the testing methods used at the University of Michigan are summarized in the appendix.

TEST MATERIAL

The available information concerning the disc may be summarized as follows:

Manufacturer:

The Universal-Cyclops Steel Corporation, Titusville, Pa.

Heat number:

B-10429

Chemical composition:

The chemical composition of Heat B-10429 was reported to be the following percentages by the manufacturer:

C	Mn	Si	Cr	Ni	Mo	W	Cb	Ti	S	P
0.33	1.14	0.65	19.10	9.05	1.35	1.14	0.35	0.16	0.015	0.016

Fabrication procedure:

A billet from a 10,000-pound arc-furnace heat was directly upset to produce a disc approximately 19 3/4 inches in diameter by 3 1/4 inches thick. The finishing temperature for this operation was 1640° F.

Heat treatment:

The as-forged disc was reheated to 1200° F and air cooled for stress relief.

Sampling:

The complete disc was shipped to Mr. H. C. Cross, Research Supervisor of National Defense Research Council, Project Number 8. The NDRC code number assigned to the disc was NR-46B. Figure 1 shows the location of the samples cut from the disc and the code system identifying the coupons. The letters X, Y, and Z refer to the location of the test coupons in respect to the flat faces of the disc. One surface of the coupons marked X and Z was the outside surface of the forging; while the Y coupons were taken from the center third of the forging.

The triangular sections D, E, and F and coupons 18X, 18Y, 19X, 19Y, 20X, 20Y, 21X, 4X, 4Y, 5X, and 5Y were supplied to the University of Michigan for the NACA test program. The triangular sections D, E and F were sampled as indicated in figure 1 so as to provide more specimens than in those cut at Battelle.

RESULTS

The data obtained are compiled as a series of tables and figures.

Hardness Survey

The Brinell hardness of the coupons cut from various locations in the disc was uniform, ranging only from 202 to 209. (See table I.) A Rockwell hardness survey of sample 20X (figure 2) showed that the hardness was highest near the rim at the surface exposed to the forging hammer. The interior of the disc near the center was softest. The hardness variations were quite small, considering the size of the disc and the work-hardening tendency of the alloy.

Short-Time Tensile Properties

Tensile tests at room temperature on specimens from several locations in the disc indicate uniform physical properties for the large forging. (See table I.) Radial specimens had slightly lower strength and higher ductility than the tangential specimen. (Sufficient specimens were not available for a similar survey of uniformity of properties at 1200° and 1350° F.) The values obtained are normal for this material with little or no cold work.

W-74

The stress-strain curves from which elastic properties were obtained are included as figure 3.

Rupture Test Characteristics

Radial specimens from the rim of the center plane of the disc had rupture strengths at 1200° F of 40,000 and 34,000 pounds per square inch for fracture in 100 and 1000 hours, respectively. Corresponding values at 1350° F were 23,000 and 15,500 pounds per square inch. The rupture test data (table II) show high elongation and reduction of area to fracture.

At 1200° F the stress-rupture time curve (figure 4) was a straight line. Instability, however, caused a break in the 1350° F curve. Some erratic values were obtained in which the specimens fractured at shorter time periods than those defined by the curves of figure 4 and were characterized by low elongation and reduction of area. The stress-rupture time relationships were, however, uniform for samples from a large forging.

While differences in time for rupture of specimens from various locations in the disc were observed, there was not a consistent relationship to the position of the specimen in the disc.

Time for Deformation Characteristics under Stress

A convenient method of describing the high-temperature strength of a material is by curves of stress versus the time required for various total deformations. Such information supplemented by a stress-rupture time curve gives design engineers a complete picture of the expected performance of an alloy. This information for the 19-9 DL disc material is incorporated in figures 5 and 6 for deformations of 0.1, 0.2, 0.5, and 1.0 percent at 1200° and 1350° F for time periods up to 2000 hours. Additional curves showing the time of transition from a minimum creep rate to the increasing rate of third-stage creep have been added so as to show when rapid elongation to failure starts.

The deformation data were obtained from time-elongation curves from the constant-stress creep tests (figures 7 and 8) and the rupture tests (figures 9, 10, 11 and 12). The data used from these curves are tabulated in tables III and IV. At 1200° F, only a few points on the 1.0-percent curve were obtained from the rupture tests because of the high stresses and rapid deformation rates of the rupture-test specimens. There was no indication of third-stage creep after 2000 hours at 1200° F under a stress of 22,500 pounds per square inch; so it was necessary to base the transition curve on rupture-test data.

The behavior of the material at 1350° F was different, in that third-stage creep occurred at relatively short time periods, even under low stresses and creep rates. The quite erratic total deformation data at this temperature, together with the lack of agreement between creep and rupture-test time-elongation curves, may be attributed both to the instability of the material and to differences between samples.

Three of the creep tests at 1350° F were conducted by NDRC Project NRC-8. In addition, a constant-stress test at 800° F and three tests at 900° F also were conducted by NRC-8 on samples from the disc. The results of these latter tests (table V) are reported as percentage deformations and creep rates. The relatively high deformation for short time periods is due to the low yield strength of the disc material. Failure did not occur under the high stresses because of the rapid strengthening due to the strain hardening at these temperatures.

Creep Strengths

Many engineers are accustomed to base designs on creep rates, especially for long periods of service. The logarithmic stress-creep rate curves usually used for this purpose have been prepared as figure 13.

At 1200° F the stresses for 0.01 and 0.10 percent per 1000-hour creep rates were 11,000 and 25,000 pounds per square inch, respectively. The transition curve of figure 5 indicates that these values are safe for the usual extrapolations.

Since all the creep tests at 1350° F showed third-stage creep, the creep data cannot be relied on for extrapolation. For instance, the probable 0.01 percent per 1000-hour value for minimum creep rates would be about 3000 pounds per square inch. Extrapolation of the transition curves of figure 6 indicates that increasing creep rates under this stress would be encountered after only about 2000 hours.

Stability Characteristics

After creep-testing, the room-temperature tensile properties of the completed creep-test specimens (table VI) were similar to those of the original material. The yield strength decreased slightly, while the ductility was somewhat higher. A change in impact strength occurred, with the strength of the 1350° F creep specimen being only half that of the original material. The creep specimens did not change in hardness, although there was some decrease in the long-time rupture test specimens.

In general, the microstructure of the disc was quite uniform. The grain size range was 4 to 6, with different sizes predominating in the various samples examined. The appearance of the banded excess constituents depended on the relation of the flow of the metal to the plane of the sample. Typical extremes in appearance are shown in figure 14. The variation in the number of generally precipitated particles in the matrix also is shown.

The tests at 1200° F did not change the structure noticeably (figures 15 and 16), except for the grain distortion at the fracture of the rupture specimens. There was no cracking on the surface of the rupture test specimen. The number of twins increased during testing at 1350° F, together with considerable agglomeration of excess constituents removing the grain boundary precipitates. A large number of cracks on the surface of the rupture test specimen indicated surface instability as well as structural instability at the higher test temperature.

DISCUSSION OF RESULTS

The stress-rupture and time-deformation data provide as nearly complete design information as can be obtained from laboratory constant-stress tension tests. The completeness of the data will permit an accurate estimation of the properties of other large forgings of 19-9 DL steel, in the future, by only a few tests, since the shapes of the various curves have been established. The data should be used with caution until further check tests are available on other discs, since experience has shown that high-temperature properties of such alloys may be subject to variations between heats and with different methods of production.

The large forging had quite good high-temperature strengths at 1200° F, although they were not as high as had been hoped for on the basis of previous test results on bar stock. If the disc had been hot-cold worked below the normal hot-working temperatures, as is possible with recently developed equipment, the properties would have been increased to a considerable extent, at least for the shorter time periods. The low strength and early onset of third-stage creep at 1350° F indicate that large forgings of this alloy have only limited applicability at this temperature to low-stress service.

In general, the properties of the large disc appeared to be very uniform for a forging of the size considered. At 1200° F the rupture-test data were quite uniform and the stress-time-for-deformation test results gave a smooth curve. At 1350° F, however, the data were considerably more erratic. This probably was due to one or both of two conditions. The properties may have been more sensitive to structural variations at 1350° F than at 1200° F. A more probable reason is that the greater instability caused variation in test results, as well as exaggerating the structural differences.

The hardness survey and the slightly higher tensile properties of the tangential specimens indicated a small amount of cold work at the rim of the disc. At temperatures above the range where strain hardening predominates, cold work contributes to instability and lower strength. This may account in part for the apparent low deformation strength of the rupture-test specimens at 1350° F. Apparently, the 1200° F properties were not influenced by the small differences present. The relation between excess constituents and specimen direction, as well as variations in distribution of excess constituents, also may have had a minor effect.

The results indicated that the material was very stable at 1200° F, and probably the major change occurring was a strengthening effect as deformation occurred under stress. At 1350° F, however, agglomeration of the excess constituents took place, as well as a probable annealing effect. These two changes are believed to account for the early onset of third-stage creep. The severe intergranular cracking of the surface of the rupture test specimens suggests that surface instability also may have been partially responsible for the apparently low deformation strength of the rupture-test specimens. The ratio of surface to cross-sectional area was much larger in the 0.160-inch-diameter rupture-test specimens than in the 0.505-inch-diameter creep specimens, with a consequent possible greater effect from surface instability.

CORRELATION OF PROPERTIES OF 19-9 DL ALLOY IN VARIOUS FORMS

Data are available for 19-9 DL alloy fabricated by several methods, although a considerable portion of the investigation of these factors is still in progress. The properties of alloys of this type are known to vary to a considerable extent depending on the condition of the metal after the particular fabrication procedure used. The relationship between bar stock and large forgings processed in an analagous manner is of particular importance. Studies on large forgings are expensive and time consuming. If related results from studies on bar stock are possible, the development of the best possible methods of treating these types of steels and the prediction of probable physical properties in various commercial shapes would be considerably simplified.

In general, hot-rolled bar stock has higher strength in tensile tests and at the higher rates of deformation in creep and rupture tests at 1200° F. (See table VII.) The 1000-hour deformation strengths are very similar for the large disc and for the hot-rolled bar stock. The shorter time rupture strengths and the shorter time deformation strengths for total deformations of 0.5 and 1 percent are higher for bar stock. For total deformation of 0.1 and 0.2 percent there is practically no difference between the two forms.

The comparable data at 1350° F are meager. The few available time-deformation strengths (table VII) indicate that, in the case of the 19-9 DL alloy, bar stock is weaker than large disc material, especially for time periods of the order of 1000 hours. This is due to the early onset of third-stage creep in relatively few hours at low stresses.

Essentially, these data indicate that hot-rolled bar stock and large forgings will have similar rupture and deformation characteristics at 1200° F for time periods of 1000 hours or for total deformations of 0.1 and 0.2 percent at shorter time periods. The large forgings will have less strength at high rates of deformation and for shorter time periods. The properties of solution-treated bar stock are even more similar to the large forging. These relationships are accentuated when the properties are altered by the introduction of cold work at temperatures below the normal hot-working temperatures. This is clearly shown in figure 17, which briefly compares the room-temperature yield strengths and 1200° F rupture strengths of a number of 19-9 DL materials. In most cases hot-cold work increased yield strength at room temperatures and 10- and 100-hour rupture strengths with relatively little effect on the 1000-hour rupture strength.

The comparable data for 19-9 DL alloy at 1350° F (table VIII) are not nearly so extensive as at 1200° F. There was not much difference between the large disc and the hot-cold worked turbosupercharger wheels on the basis of their 100- and 1000-hour rupture strengths. The bar stock had much greater strengths, although this is not considered typical, since this first small induction heat, R1803, had abnormally high strengths in comparison to that which has since been obtained from commercial heats. Although data are not available, it is certain that the cold-worked materials would have much higher rupture strengths than the large disc for time periods less than 100 hours. The cold work would be effective at the shorter time periods, as is the case in tensile tests.

These comparisons have been based on the disc investigated. Hot-cold worked discs produced by recently developed equipment would have higher short-time properties. The level of these properties would probably be between those obtained on hot-rolled and hot-cold worked bar stock. The effect should be quite similar to that obtained in turbosupercharger wheels.

Although the comparison figures and tables do not show ductility values, the cold-worked condition has only about 2 percent elongation and reduction in area in the rupture tests. The hot-worked and solution-treated materials have much greater ductility to fracture. This difference in elongation to fracture suggests that the time-deformation characteristics may be considerably better in cold-worked materials than for the hot-worked or solution-treated conditions. If the total elongation to fracture is low, then the deformation rates must be lower than in the case of materials with high elongation to fracture in the same time periods.

CONCLUSIONS

The properties of one large disc of 19-9 DL steel in the as-forged and stress-relieved condition have been determined under constant-tension stress conditions for time periods up to 2000 hours at 1200° and 1350° F. The data described the short-time tensile test, rupture-test and time-deformation characteristics. The results are believed to be quite typical for the alloy in the form of hot-worked discs, although some probable variation from disc to disc should be taken into consideration when using the data for design purposes.

Analysis of the results and comparison with other data for 19-9 DL steel lead to the following conclusions:

1. The disc had good properties at 1200° F, although the short-time strengths were quite low in comparison with those developed in cold-worked material.

2. The load-carrying ability at 1350° F was comparatively low, due to instability and the early onset of third-stage creep.

3. For this type of alloy, hot-rolled bar stock has properties similar to the large disc, except that the short-time tests at high rates of deformation give somewhat higher strength for bar stock.

4. Cold working of similar 19-9 DL steel discs by recently developed equipment would probably develop high yield strengths and high short-time rupture strengths.

5. The superiority in rupture strength at 1200° F induced by cold work gradually decreases with time until it becomes equal to those of hot-worked and annealed conditions at about 1000 hours.

Department of Engineering Research
University of Michigan
Ann Arbor, Mich., January 17, 1945.

W-74

REFERENCES

1. Freeman, J. W., Rote, F. B., and White, A. E.: High Temperature Characteristics of 17 Alloys at 1200° and 1350° F. NACA ACR No. 4C22, 1944.

2. White, A. E., Freeman, J. W., and Rote, F. B.: Physical Data on Certain Alloys for High Temperature Applications. NACA ACR No. 3D28, 1943 (Reprinted March 1944).

APPENDIX

TESTING PROCEDURE DETAILS

Hardness Testing

The Brinell hardness values reported were made on flat surface ground on the shoulders of the room temperature tensile test specimens. The hardness survey was made by grinding the surfaces of one of the coupons and then measuring the Rockwell "B" hardness at 1/4-inch intervals along the length of the coupon.

The hardness changes resulting from testing were studied by comparing the Vickers hardness of metallographic specimens with typical original samples from comparable locations in the disc.

Short-Time Tensile Tests

Standard 0.505-inch diameter specimens with 2-inch gage lengths were used for tensile tests. The equipment consisted of a 60,000-pound hydraulic testing machine and an extensometer system with a sensitivity of 0.000003 inch per inch.

Stress-strain data were taken at increments of 2500 pounds per square inch until the 0.2-percent offset yield strength was exceeded. The extensometer system was then removed and the specimen fractured at a constant head speed of 0.03 inch per minute. At 1200° and 1350° F the test bar was held at temperature 1 hour before testing. Temperature control and distribution were in accordance with A.S.T.M. recommended practice for short-time high temperature tension tests.

Rupture Testing

The specimen used was 0.160-inch diameter with a 1-inch gage length. Pieces 2½ inches in length were cut from the rim ends of radial bars 18Y, 19Y, and 20Y and 18X, center end of 20Y, and from one end of tangential bars 5Y and 5X. These were split into four quarters lengthwise and machined into specimens.

The tests of less than 10 hours duration were made in the tensile machine with the specimens being held at temperature 1 hour before testing. Individual stationary units applying the stress through a simple beam and knife-edge system were used for the longer duration tests. Twenty-four hours were allowed for temperature adjustments prior to application of the stress. Time-elongation data were obtained by measuring the "drop of the beam" during the tests.

Time for Deformation Data at 1200° and 1350° F

Time-elongation curves were obtained from constant-stress tension tests at stresses ranging from those of the rupture tests to those requiring 2000 hours to cause 0.1 percent total deformation. All tests except the rupture tests were made in creep-test units on 0.505-inch diameter specimens with an extensometer attached to the gage length of the specimens. The stresses were selected to cause total deformation of 0.1, 0.2, 0.5, and 1 percent in various time periods up to 2000 hours. Many of the tests were discontinued at time periods less than 2000 hours when it was evident that the next highest total deformation value desired would not be reached in 2000 hours.

The rupture-test time-elongation curves were adjusted for total deformation by correcting for initial deformation with tensile test stress-strain data. This procedure was necessary since the drop-of-the-beam method does not measure the deformation occurring when the stress is applied. While this method was not as accurate as the high precision creep test, it makes the rupture-test curves more useful for total deformation studies.

Stability Tests

Creep test specimens from the longer duration tests were subjected to room-temperature tensile, impact, and hardness tests. The tensile tests were run the same way as those on original samples. Impact specimens were prepared by machining the largest square bar possible from the gage length of the creep specimens, 0.365-inch square, and using a V-notch 0.050-inch deep. Two such specimens were obtained for Izod type tests. Hardness determinations were made on metallographic specimens with a Vickers machine.

Samples taken lengthwise of the specimens at the middle of the creep specimens and at the fracture of the rupture-test specimens were examined metallographically. The etching reagent used was aqua regia in glycerine.

W-74

TABLE I

SHORT-TIME TENSILE PROPERTIES OF THE 19-9 DL ALLOY FORGED DISC

Specimen number	Specimen position	Temperature (°F)	Tensile strength (lb/ sq in.)	Offset yield strengths (lb/sq in.)			Proportional limit (lb/sq in.)	Elongation % in 2 in.	Reduction of area (percent)	Brinell hardness
				(0.02%)	(0.1%)	(0.2%)				
				Surface Planes						
18X	Radial	Room	105,250	39,000	49,500	54,000	27,000	34.0	33.3	206
19X	---do.---	--do.--	104,750	38,000	49,500	54,500	26,000	29.0	28.5	207
[1]20Z	---do.---	--do.--	105,100	------	50,550	54,320	----------	34.5	41.8	---
[1]23Z	---do.---	--do.--	106,400	------	51,920	55,300	----------	34.5	31.5	---
5X	Tangential	--do.--	107,250	46,500	57,500	62,000	31,000	19.0	19.9	209
[1]18Z	Radial	900	80,800	------	35,800	38,000	----------	29.0	24.8	---
[1]19Z	---do.---	900	79,750	------	36,420	38,410	----------	26.0	24.8	---
EBX	---do.---	1200	57,875	------	35,500	37,900	20,000	34.0	47.5	---
FBX	---do.---	1350	38,100	------	29,250	31,100	15,000	45.0	69.3	---
				Center Plane						
18Y	Radial	Room	103,250	40,600	51,000	55,000	29,000	25.0	23.7	202
19Y	---do.---	--do.--	103,500	39,500	50,000	55,000	24,000	25.5	25.6	208
5Y	Tangential	--do.--	107,750	44,200	55,500	60,000	32,000	22.5	21.3	207

[1]NDRC Project NRC-8 tests.

TABLE II

1200° AND 1350° F RUPTURE TEST CHARACTERISTICS OF THE 19-9 DL

ALLOY FORGED DISC

Specimen mark	Specimen location	Temperature (° F)	Stress (lb/sq in.)	Rupture time (hr)	Elongation % in 1 in.	Reduction of area (percent)
20Y	C.R.R.	1200	59,040	S.T.T.T.	36.0	32.0
20Y	--do.--	1200	54,000	1.02	32.0	43.7
20Y	--do.--	1200	49,000	4.43	37.0	51.0
18Y	--do.--	1200	40,000	25.	11.0	25.6
18Y	--do.--	1200	37,500	290.	39.0	53.6
18Y	--do.--	1200	35,000	966.5	16.0	29.8
18Y	--do.--	1200	33,500	604.5	9.0	28.8
20Y	--do.--	1200	33,500	1565.0	15.0	46.5
20Y(C)	C.R.C.	1200	40,000	250	21.0	53.0
18X	S.R.R.	1200	40,000	136	24.0	57.0
5Y	C.T.R.	1200	40,000	168.5	28.0	58.6
5X	S.T.R.	1200	40,000	37.5	30.0	63.2
20Y	C.R.R.	1350	41,600	S.T.T.T.	16.0	48.3
20Y	--do.--	1350	36,000	0.68	38.0	62.5
20Y	--do.--	1350	30,000	4.55	42.0	70.4
19Y	--do.--	1350	25,000	36.0	31.0	55.3
19Y	--do.--	1350	22,500	135.0	34.0	64.7
19Y	--do.--	1350	20,000	277.0	30.0	67.6
19Y	--do.--	1350	17,500	663.5	24.0	38.0
20Y	--do.--	1350	14,500	1404.0	23.0	32.0
20Y(C)	C.R.C.	1350	22,500	78.0	31.0	65.5
18X	S.R.R.	1350	22,500	124.5	28.0	63.2
5Y	C.T.R.	1350	22,500	156.0	31.0	66.2
5X	S.T.R.	1350	22,500	133.5	26.0	68.0

			Rupture strength				
			Stress for rupture at indicated time periods (lb/sq in.)				
			(1 hr)	(10 hr)	(100 hr)	(1000 hr)	(2000 hr)
---	C.R.R.	1200	53,500	46,000	40,000	34,000	33,000
---	C.R.R.	1350	34,500	28,000	23,000	15,500	13,500

S.T.T.T. short-time tensile test.
C.R.R. center plane radial specimens at rim of disc.
C.R.C. center plane radial specimens at center of disc.
S.R.R. surface plane radial specimens at rim of disc.
C.T.R. center plane tangential specimens at rim of disc.
S.T.R. surface plane tangential specimens at rim of disc.

TABLE III

TIME-DEFORMATION DATA AT 1200° F FOR 19-9 DL ALLOY FORGED DISC

Specimen number	Stress (lb/sq in.)	Initial deformation (percent)	Time in hours for indicated total deformation (0.1%)	(0.2%)	(0.5%)	(1.0%)	Transition Time (hr)	Transition Deformation (percent)	Rupture Data Time (hr)	Rupture Data Elongation (percent)
20X	11,000	0.055	[1]3000	---	---	---	---	---	---	---
DY-2	12,500	.057	275	---	---	---	---	---	---	---
21X	15,000	.0775	36	[1]3250	---	---	---	---	---	---
FAY-2	17,500	.0841	2.3	725	---	---	---	---	---	---
DX	20,000	.0935	0.1	106	---	---	---	---	---	---
DY-1	22,500	.1075	------	36	1750	---	---	---	---	---
EAX	25,000	.132	------	5.2	214	---	---	---	---	---
FAY-1	27,500	.54	------	0.7	43	360	---	---	---	---
20Y	33,500	.21	------	---	---	5	925	5	1565	15
18Y	33,500	.21	------	---	---	10	525	4	604.5	9
18Y	35,000	.25	------	---	---	2.5	500	5	966	16
18Y	37,500	.36	------	---	---	1.	155	7	290	39
18Y	40,000	---	No time-elongation curve						25	11
18X	40,000	.5	------	---	---	---	68	4.5	136	24
5Y	40,000	.5	------	---	---	---	115	7	168.5	28
5X	40,000	---	No time-elongation curve						37.5	30
20Y-C	40,000	.5	------	---	---	---	130	7.8	250	21

[1]Extrapolated from creep rates.

TABLE IV

TIME-DEFORMATION DATA AT 1350° F FOR 19-9 DL ALLOY FORGED DISC

Specimen number	Stress (lb/sq in.)	Initial deformation (percent)	Time in hours for indicated total deformation				Transition		Rupture data	
			(0.1%)	(0.2%)	(0.5%)	(1.0%)	(hr)	Deformation (percent)	Time (hr)	Elongation (percent)
[1] 23X	6,500	0.039	285	1560	----	----	1225	0.17	--	---
FBY-2	7,500	.041	205	1300	----	----	1125	.18	--	---
[1] EBY-1	10,000	.052	35	550	1715	----	700	.23	--	---
[1] 22X	12,000	.083	1.8	44	610	1185	550	.46	--	---
22Y	15,000	.099	---	37	185	510	360	.74	--	---
EBY-2	17,500	.095	---	6.5	---	---	---	----	--	---
FBY-1	22,500	.126	---	---	6.5	22.5	---	----	--	---
20Y	14,500	.08	---	---	30	235	190	.9	1404	23
19Y	17,500	.10	---	---	12	45	150	1.4	663.5	24
19Y	20,000	.11	---	---	7	19	90	2.5	277	30
19Y	22,500	.135	---	---	---	10	50	2.3	135	34
19Y	25,000	----	No time-elongation curve						36	31
18X	22,500	.135	---	---	---	12	75	3.7	124.5	28
5Y	22,500	.135	---	---	---	12	75	3.7	156	31
5X	22,500	.135	---	---	---	12	75	3.7	133.5	26
20Y-C	22,500	.135	---	---	---	3	47	5	78	31

[1]Tests conducted by National Research Council Project No. 8.

W-74

TABLE V

DEFORMATION CHARACTERISTICS AT 800° AND 900° F FOR 19-9 DL ALLOY FORGED DISC

[PROJECT NRC-8 DATA]

Specimen number	Temperature (° F)	Stress (lb/sq in.)	Deformation on loading (percent)	Deformation rate (percent/hr)(1)	Time under stress (hr)	Total deformation (percent)
21Y-4	800	50,000	1.99	0.000032	538	3.12
21Y-3	900	40,000	.45	.000027	1729	.574
21Y-2	900	50,000	2.0	.0045	339	3.2
21Y-1	900	65,000	5.1	.0028	374	7.2

In the tests at 800° and 900° F at the lower stresses of 40,000 and 50,000 lb/sq in., the time-deformation data sometimes showed steps in the curves where the specimen deformed, then strengthened, and then later deformed at a more rapid rate. This behavior may be attributed to the stresses being above the yield strength where such occurrences may be expected.

[1]Minimum rate (at end of test).

TABLE VI

EFFECT OF 1200° AND 1350° F TESTING ON THE ROOM TEMPERATURE PHYSICAL PROPERTIES

OF THE 19-9 DL ALLOY FORGED DISC

Type of test	Specimen number	Testing conditions: Temperature (° F)	Stress (lb/sq in.)	Time (hr)	Tensile strength (lb/sq in.)	Offset yield stress (lb/sq in.) (0.02%)	(0.1%)	(0.2%)	Proportional limit (lb/sq in.)	Elongation % in 2 in.	Reduction of area (percent)
Range in tensile properties of original specimens			low		103,250	38,000	49,500	54,000	24,000	19.0	19.9
			high		107,750	46,500	57,500	62,000	32,000	34.5	41.8
Creep	21X	1200	15,000	1245	106,550	29,000	43,500	50,500	15,000	32.0	28.3
Do.--	20X	1200	11,000	2000	106,450	34,000	45,000	51,000	20,000	34.5	41.9
Do.--	FBY2	1350	7,500	1780	104,450	31,000	43,000	48,000	20,000	[1]16.5	[1]13.7

Type of test	Specimen number	Temperature (° F)	Stress (lb/sq in.)	Time (hr)	Izod impact strength[2] (ft-lb)	Vickers hardness
	19Y	Original			28, 24	215-239
Creep	DY1	1200	22,500	2000	19, 20	231
Do.--	EBY1	1350	10,000	1737	14	233
Rupture	20Y	1200	33,500	1565	--------------------	224
Do.--	20Y	1350	14,500	1404	--------------------	214

[1]Fracture in gage marks.

[2]Specimens 0.365-in. sq with a 0.050-in. deep V-notch.

W-74

TABLE VII

COMPARATIVE PROPERTIES OF 19-9 DL ALLOY AS A LARGE FORGED DISC AND AS HOT-ROLLED BAR STOCK

	Large disc	Hot-rolled bar stock		
Heat number	B-10429	B10429[1]	N163[1 2]	A10753[3]
Chemical composition, percent				
C	0.33	----	0.30	0.24
Mn	1.14	----	.85	.43
Si	.65	----	.67	.49
Cr	19.10	----	18.88	19.50
Ni	9.05	----	9.31	9.06
Mo	1.35	----	1.25	1.28
W	1.14	----	1.18	1.09
Cb	.35	----	.33	.31
Ti	.16	----	.19	.25
Hot work finishing temperature, ° F	1640	1650	----	1750
Brinell hardness	202-208	----	215	211-241
Room temperature tensile properties				
Tensile strength, lb/sq in.	[4]104,700	----	117,500	114,000
0.02% offset yield strength, lb/sq in.	[4]39,275	----	54,750	45,500
0.1% offset yield strength, lb/sq in.	[4]50,400	----	64,750	------
0.2% offset yield strength, lb/sq in.	[4]54,700	-----	67,750	68,225
Elongation, percent in 2 inch	[4]30.2	----	56.2	34.7
Reduction of area, percent	[4]30.7	----	55.7	51.6
1200° F tensile properties				
Tensile strength, lb/sq in.	57,875	----	74,500	------
0.2% offset yield strength, lb/sq in.	37,900	----	40,000	------
Elongation, percent in 2 inch	34.0	----	32.0	------
Reduction of area, percent	47.5	----	32.3	------
1200° F rupture characteristics				
100-hr rupture strength, lb/sq in.	40,000	----	47,000	43,000
100-hr rupture elongation, % in 1 in.	27	----	16	20
1000-hr rupture strength, lb/sq in.	34,000	----	37,000	36,000
1000-hr rupture elongation, % in 1 in.	16	----	14	30
1200° F time-deformation strengths				
0.1% in 10 hours	16,000	----	16,000	------
0.1% in 100 hours	14,000	----	13,000	------
0.1% in 1000 hours	12,000	----	11,000	------
0.2% in 10 hours	24,000	----	25,000	------
0.2% in 100 hours	21,000	----	21,000	------
0.2% in 1000 hours	17,000	----	16,000	------

See footnotes at end of table.

W-74

TABLE VII CONTINUED

	Large disc	Hot-rolled bar stock		
Heat number	B-10429	B10429[1]	N163[1 2]	A10753[3]
1200° F time-deformation strengths (cont'd)				
0.5% in 10 hours	29,000	----	38,000	------
0.5% in 100 hours	26,000	----	31,000	------
0.5% in 1000 hours	23,500	----	24,000	------
1% in 10 hours	32,500	----	42,000	------
1% in 100 hours	29,000	----	36,000	------
1% in 1000 hours	26,000	----	28,000	------
Transition in 100 hours	39,000	----	45,000	------
Transition in 1000 hours	33,000	----	33,000	------
1350° F time-deformation strengths				
0.1% in 10 hours	11,000	11,000	------	------
0.1% in 100 hours	8,500	------	------	-------
0.1% in 1000 hours	5,000	------	------	------
0.2% in 10 hours	16,000	------	------	------
0.2% in 100 hours	12,000	12,000	------	------
0.2% in 1000 hours	7,500	------	------	------
0.5% in 10 hours	21,500	------	------	------
0.5% in 100 hours	16,000	------	------	------
0.5% in 1000 hours	11,000	9,000	------	------
1% in 10 hours	24,000	------	------	------
1% in 100 hours	18,500	------	------	------
1% in 1000 hours	12,500	------	------	------
Transition in 1000 hours	8,000	3,000	------	------
1200° F creep strengths				
0.01%/1000 hours	11,000	------	9,500	------
0.10%/1000 hours	25,000	------	22,000	------

[1]Unreported data from investigation in progress at the University of Michigan for the NACA.

[2]Universal-Cyclops Steel Corporation data.

[3]The Effect of Heat Treatment and Hot-Cold Work on the Properties of Five Alloys. By J. W. Freeman, E. E. Reynolds, A. E. White. University of Michigan Rep. No. 9, February 26, 1944.

[4]Average values for radial specimens.

W-74

TABLE VIII

EFFECT OF PROCESSING PROCEDURE ON THE ROOM TEMPERATURE YIELD STRENGTH

AND 1350° F RUPTURE STRENGTH OF 19-9 DL ALLOY

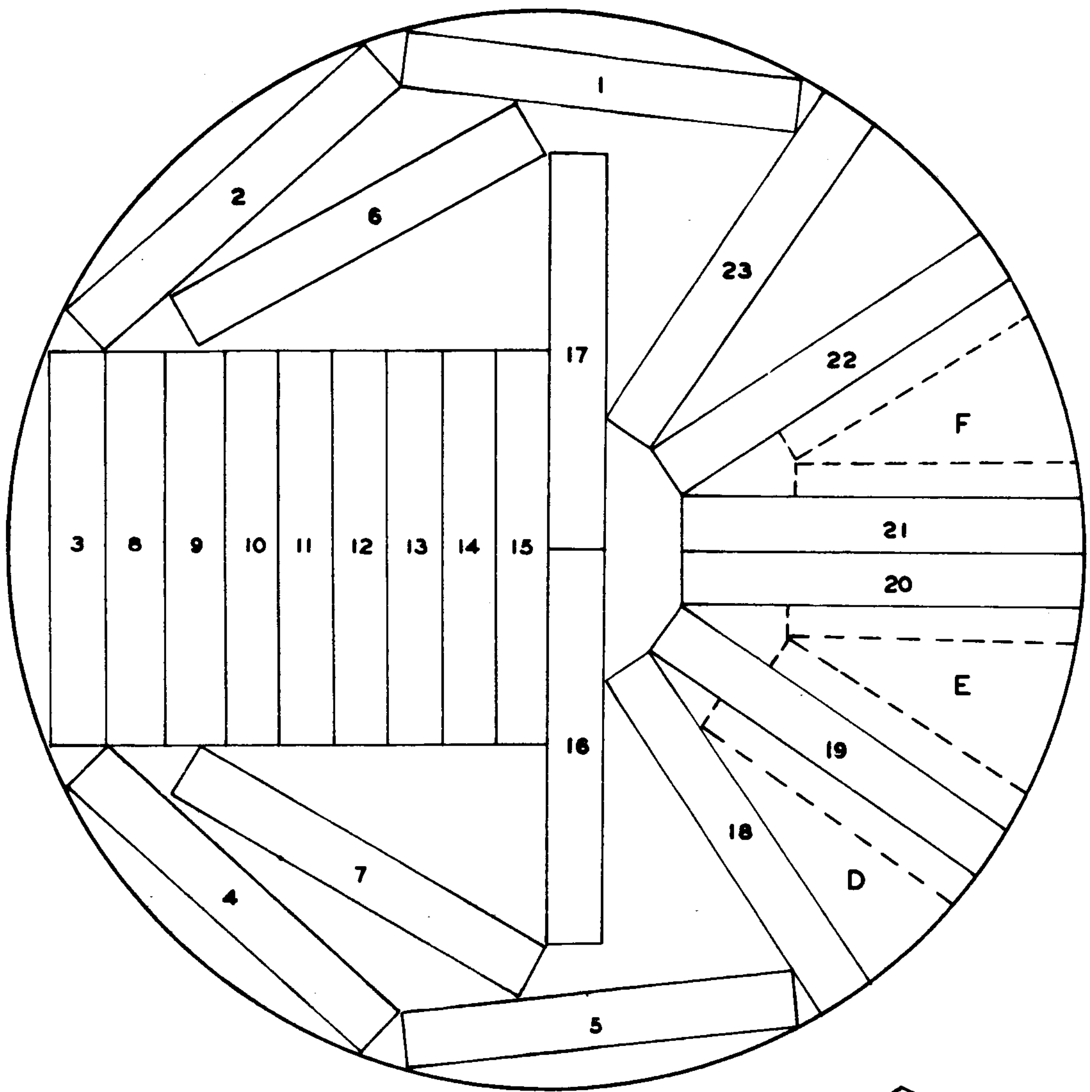
Type material	Heat number	Solution treatment			Hot-cold work		Final heat treatment		Room temperature 0.02% offset yield strength (lb/sq in.)	Rupture strength at 1350° F (lb/sq in.)	
		Temperature (°F)	Time (hr)	Cooling	Temperature (°F)	% Reduction	Temperature (°F)	Time (hr)		(100 hr)	(1000 hr)
Large disc	B10429	None	None	None	None	None	1200	2	39,275	23,000	15,500
Turbosupercharger wheel[1] (VD-1952)	B10429	None	None	None	1350	(2)	1200	4	[3]84,000	25,000	13,000
Turbosupercharger wheel[1] (VD-1957)	B10429	2100	1	Air-cooled	1350	(2)	1200	4	[3]83,500	23,000	13,500
Bar stock[4]	R1803	2100	1	Air-cooled	1200	21.35	1200	1	95,000	35,000	20,500

[1]Unreported data from investigation in progress at the University of Michigan for the NACA.

[2]Contour forging from closed dies by Steel Improvement and Forge Company standard practice for Type "B" turbosupercharger wheel forgings.

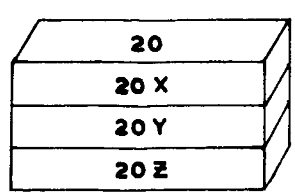
[3]General Electric Company, River Works, tests on radial specimens near the rim.

[4]See reference 1.

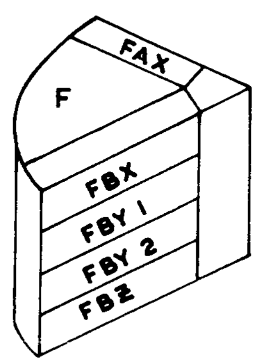


COUPONS RECEIVED FOR TESTING

18X AND Y
19X AND Y
20X AND Y
21X
4X AND Y
5X AND Y
SECTIONS D,E,F



NUMBERING OF COUPONS



LOCATION OF COUPONS CUT FROM SECTIONS D,E,F

FIGURE 1.-LOCATION OF TEST COUPONS IN 19-9 DL ALLOY FORGED DISC.

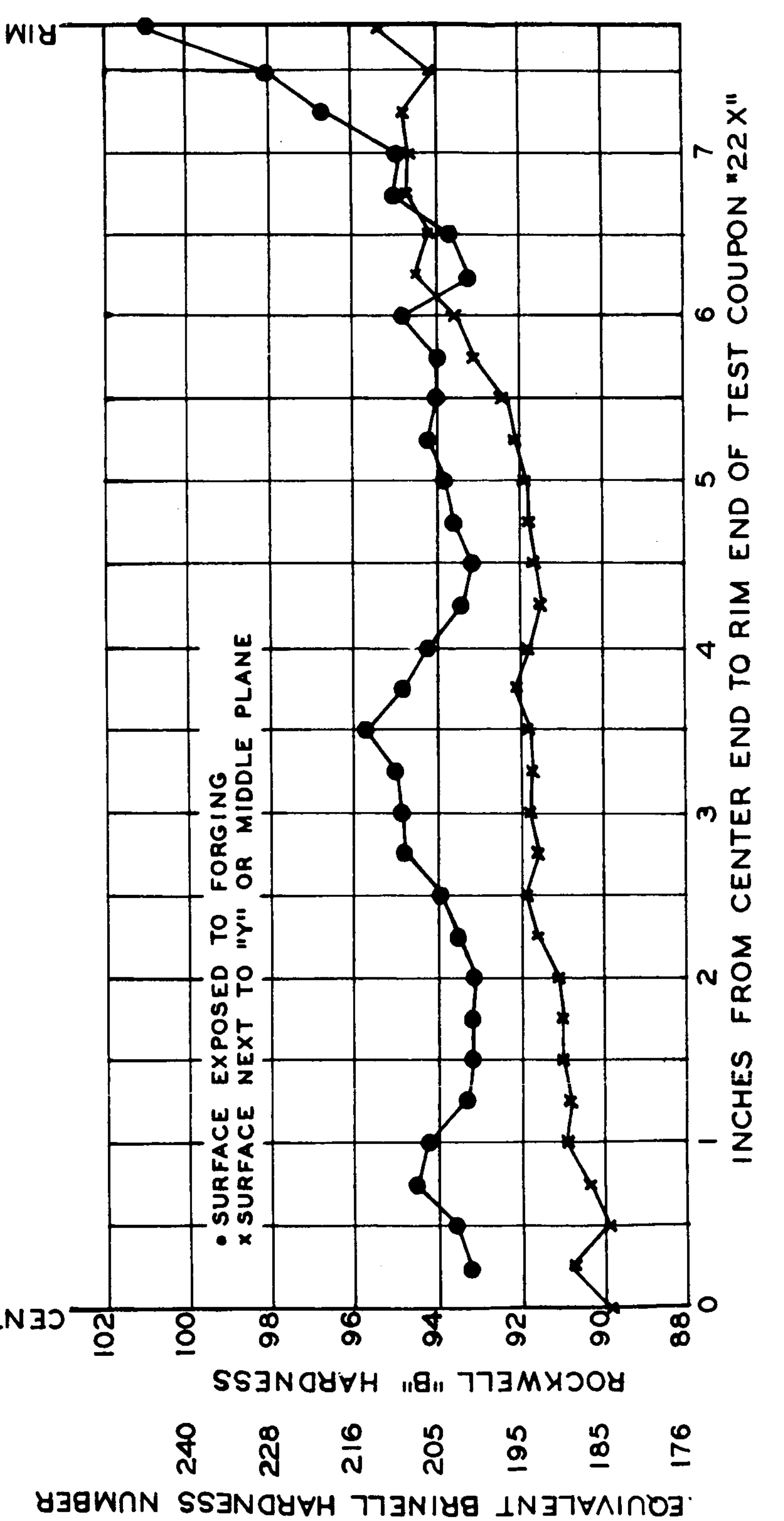


FIGURE 2.-VARIATION IN HARDNESS FROM CENTER TO RIM OF 19-9DL ALLOY FORGED DISC.

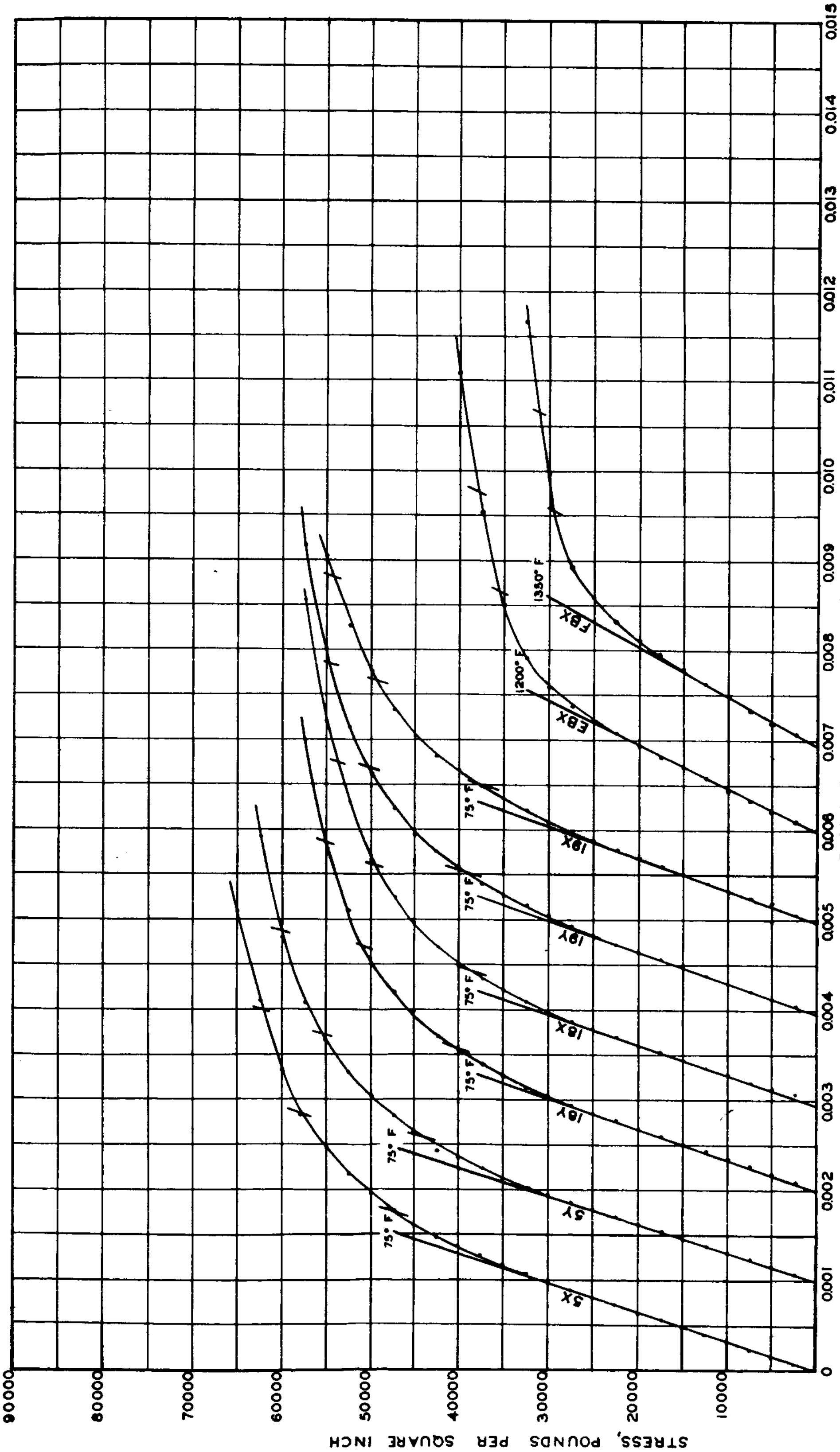
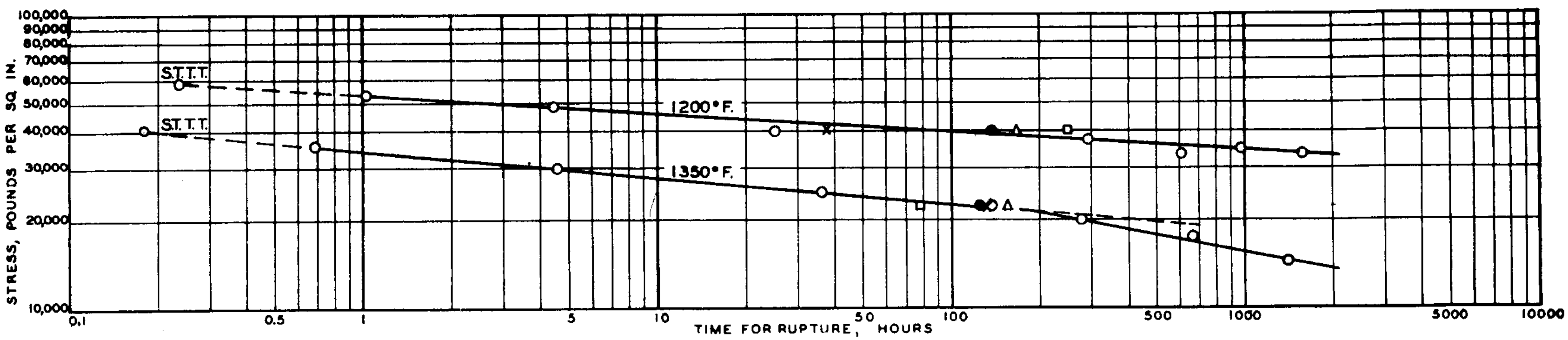


FIGURE 3. - STRESS-STRAIN CURVES FOR TENSILE TESTS ON 19-9 DL ALLOY FORGED DISC.



CODE LOCATION OF SPECIMEN IN DISC

CODE	LOCATION OF SPECIMEN IN DISC
O	CENTER RADIAL SPECIMENS AT RIM
●	SURFACE " " " "
□	CENTER " " " CENTER
X	SURFACE TANGENTIAL " " RIM
Δ	CENTER " " " "

S.T.T.T. = SHORT TIME TENSILE TEST

FIGURE 4.- STRESS-RUPTURE TIME CURVES FOR 19-9 DL ALLOY FORGED DISC.

W-74

W-74

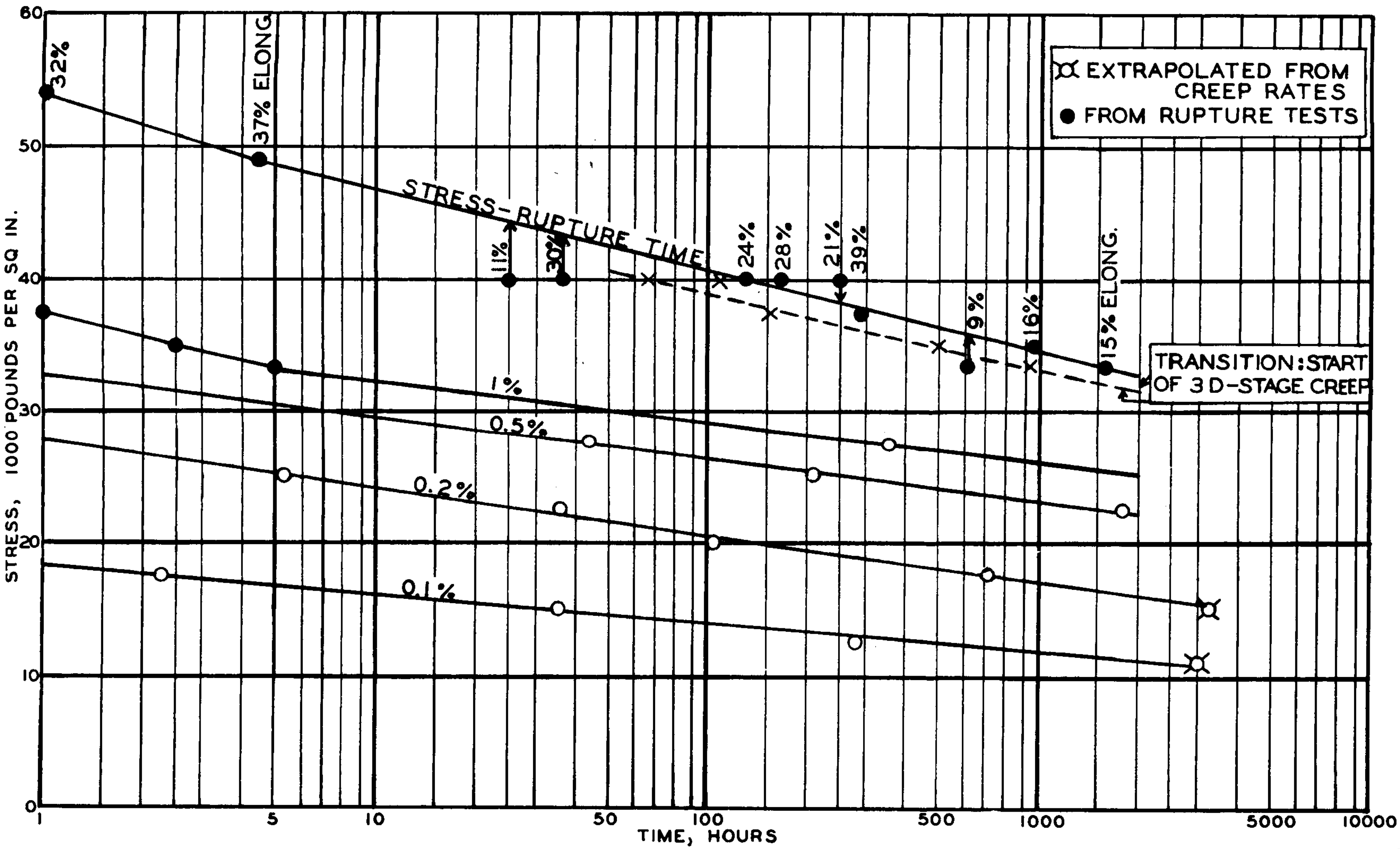


FIGURE 5.— CURVES OF STRESS-TIME FOR INDICATED TOTAL DEFORMATIONS FOR 19-9 DL ALLOY FORGED DISC AT 1200° F.

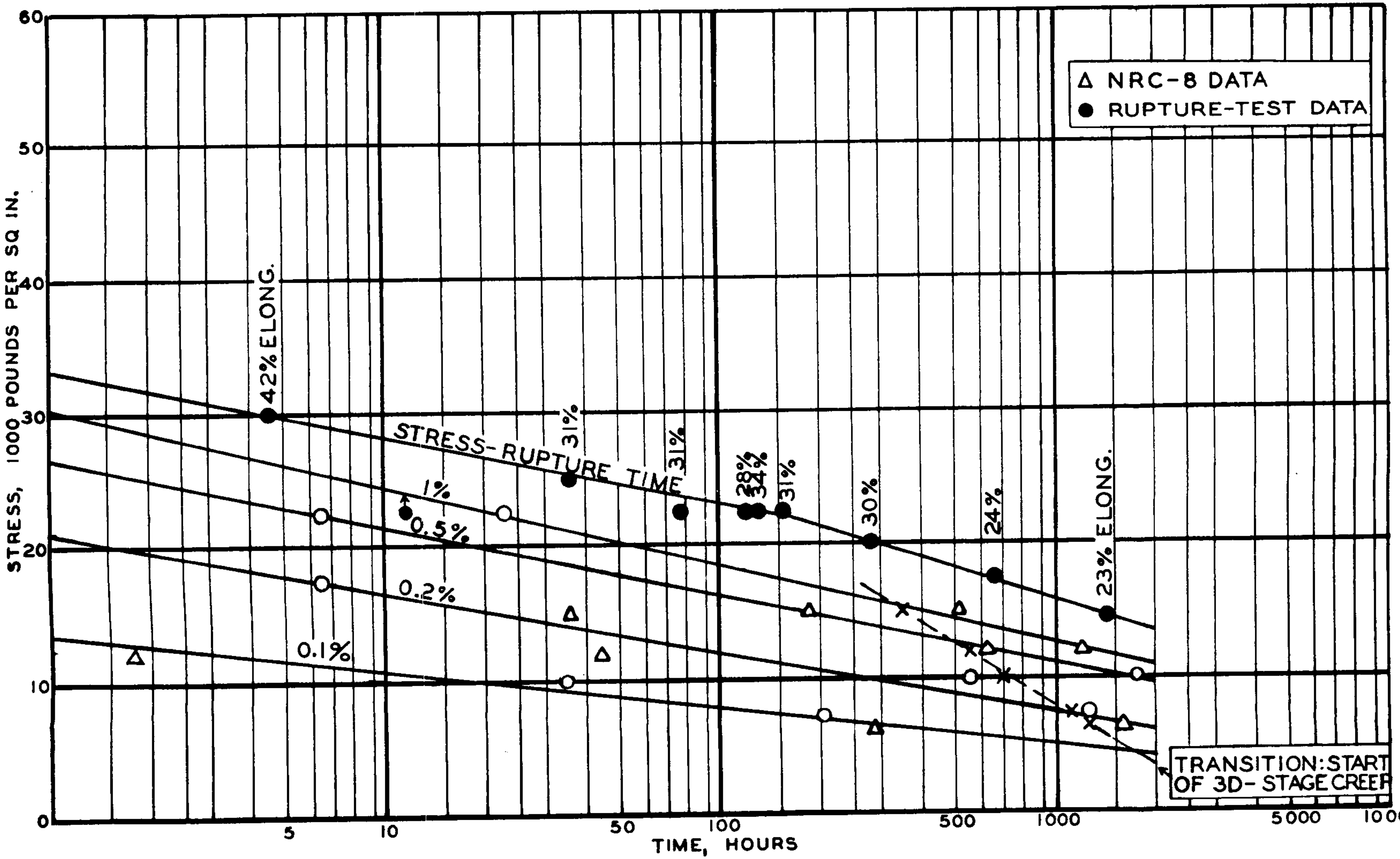


FIGURE 6.— CURVES OF STRESS-TIME FOR INDICATED TOTAL DEFORMATIONS FOR 19-9 DL ALLOY FORGED DISC AT 1350° F.

W-14

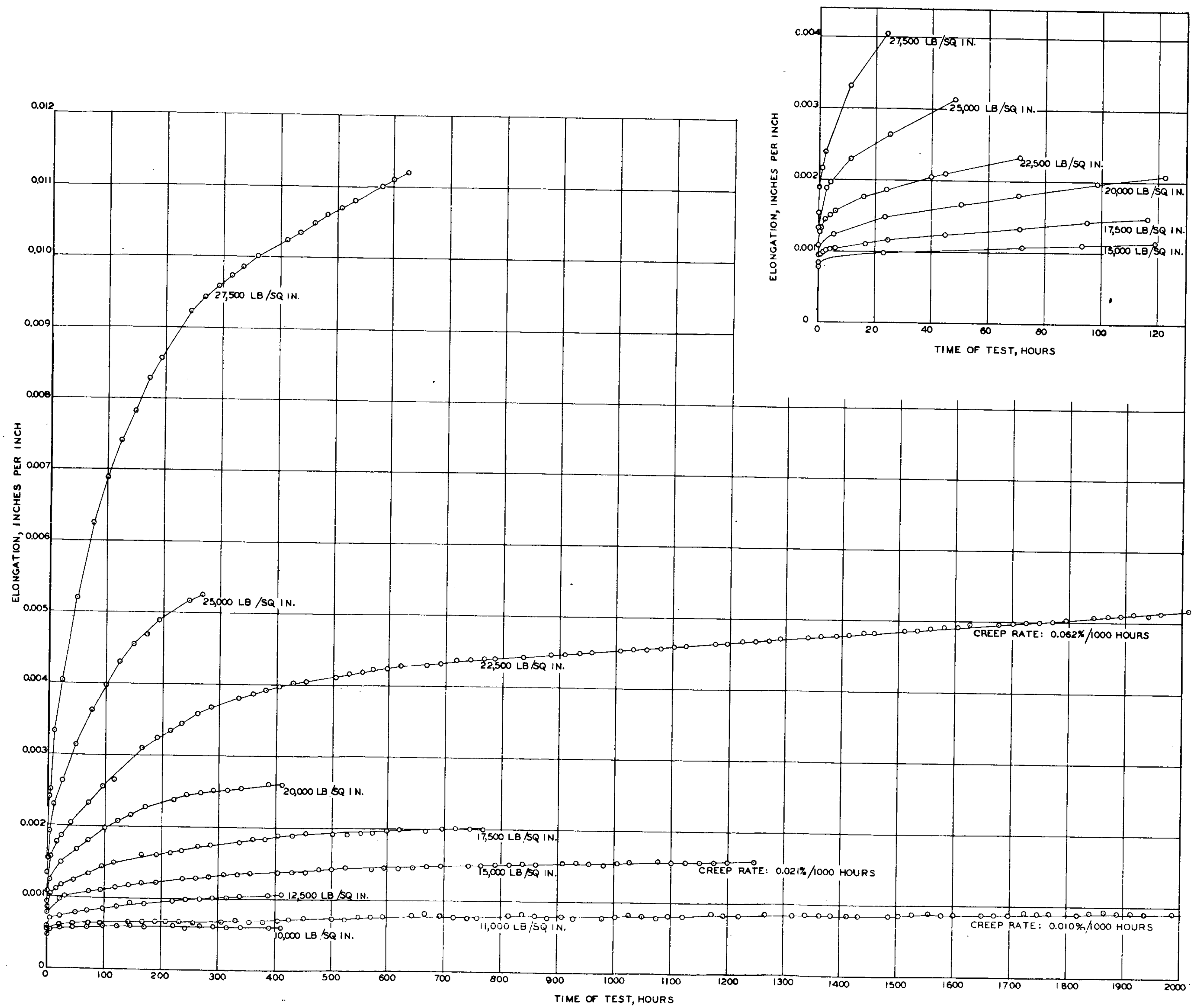


FIGURE 7. - TIME-ELONGATION CURVES FOR 19-9 DL ALLOY FORGED DISC AT 1200°F.

W-74

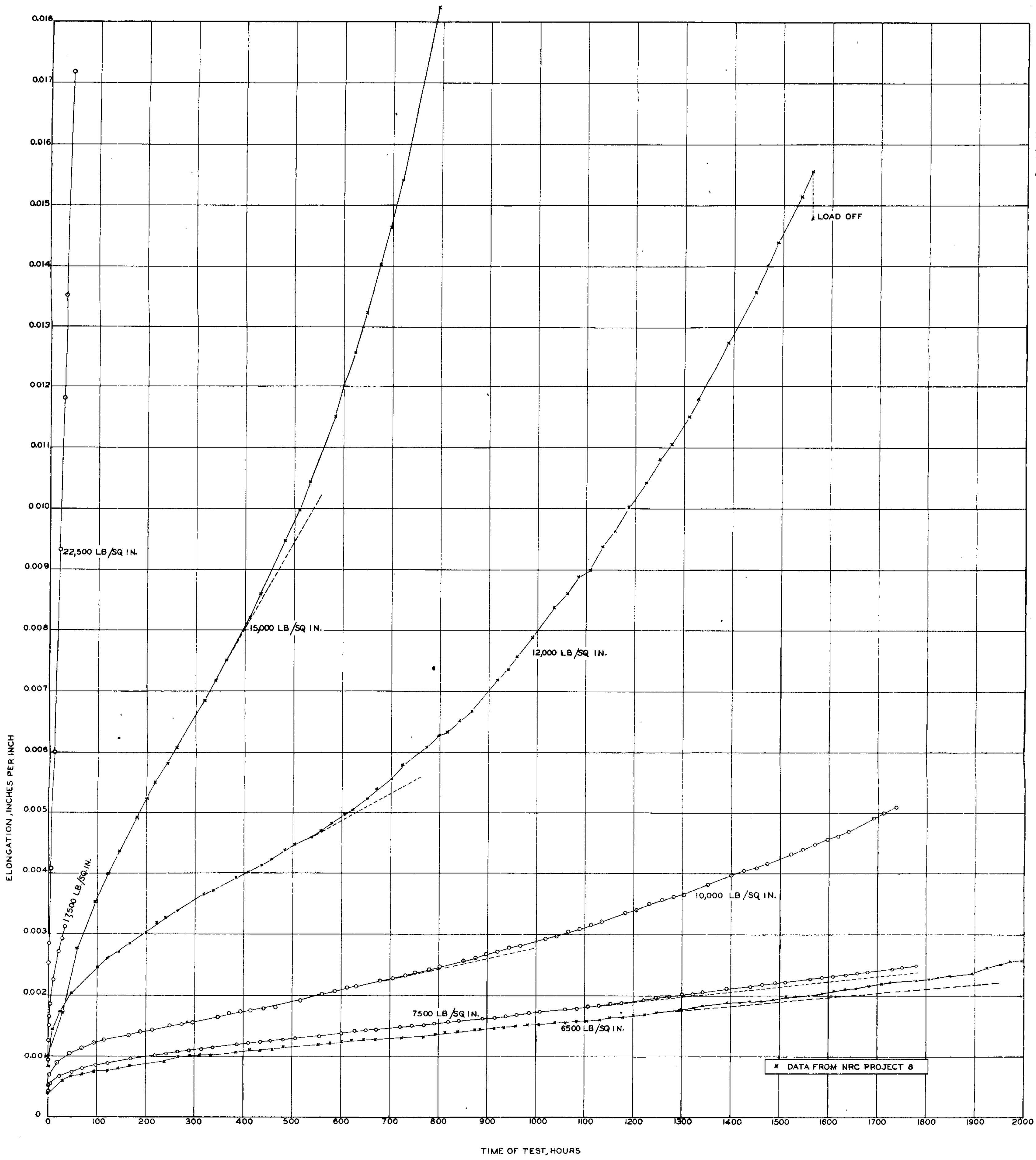


FIGURE 8.-TIME-ELONGATION CURVES FOR 19-9 DL ALLOY FORGED DISC AT 1350°F.

W-74

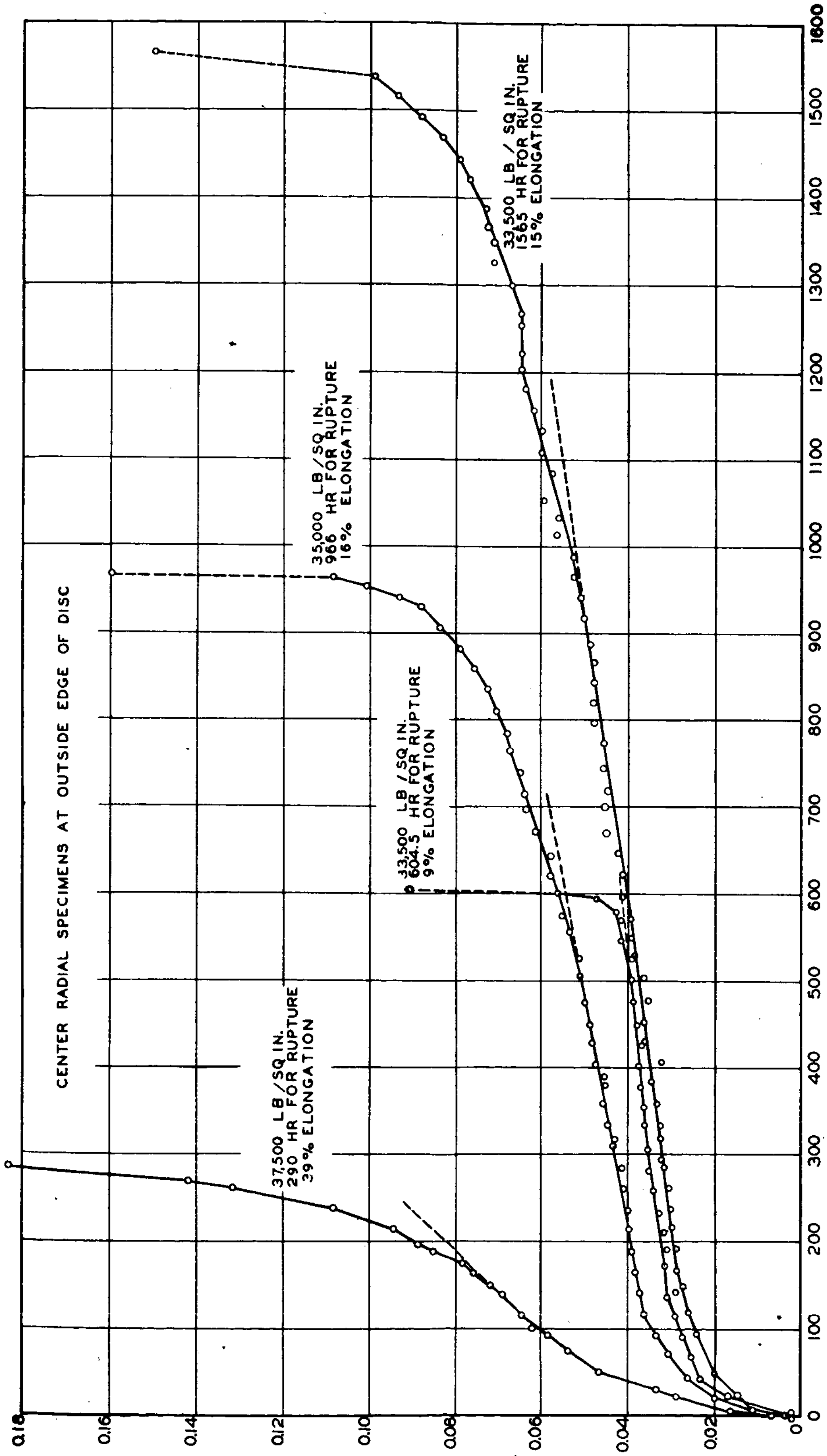


FIGURE 9. - TIME-ELONGATION CURVES FOR RUPTURE TESTS AT 1200° F ON FORGED 19-9 DL ALLOY DISC.

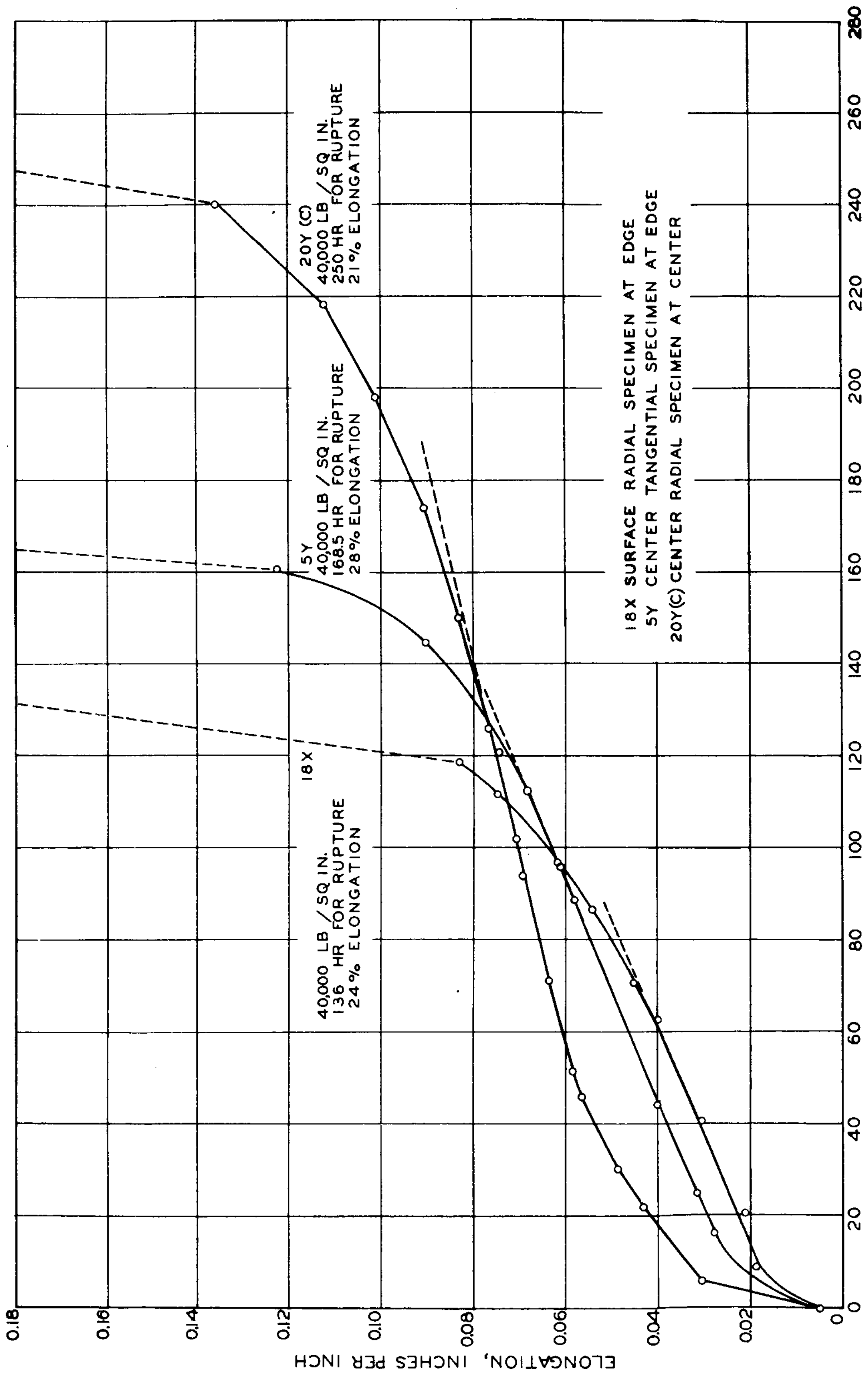


FIGURE 10.-TIME-ELONGATION CURVES FOR RUPTURE TESTS AT 1200° F ON FORGED 19-9 DL ALLOY DISC.

W- 74

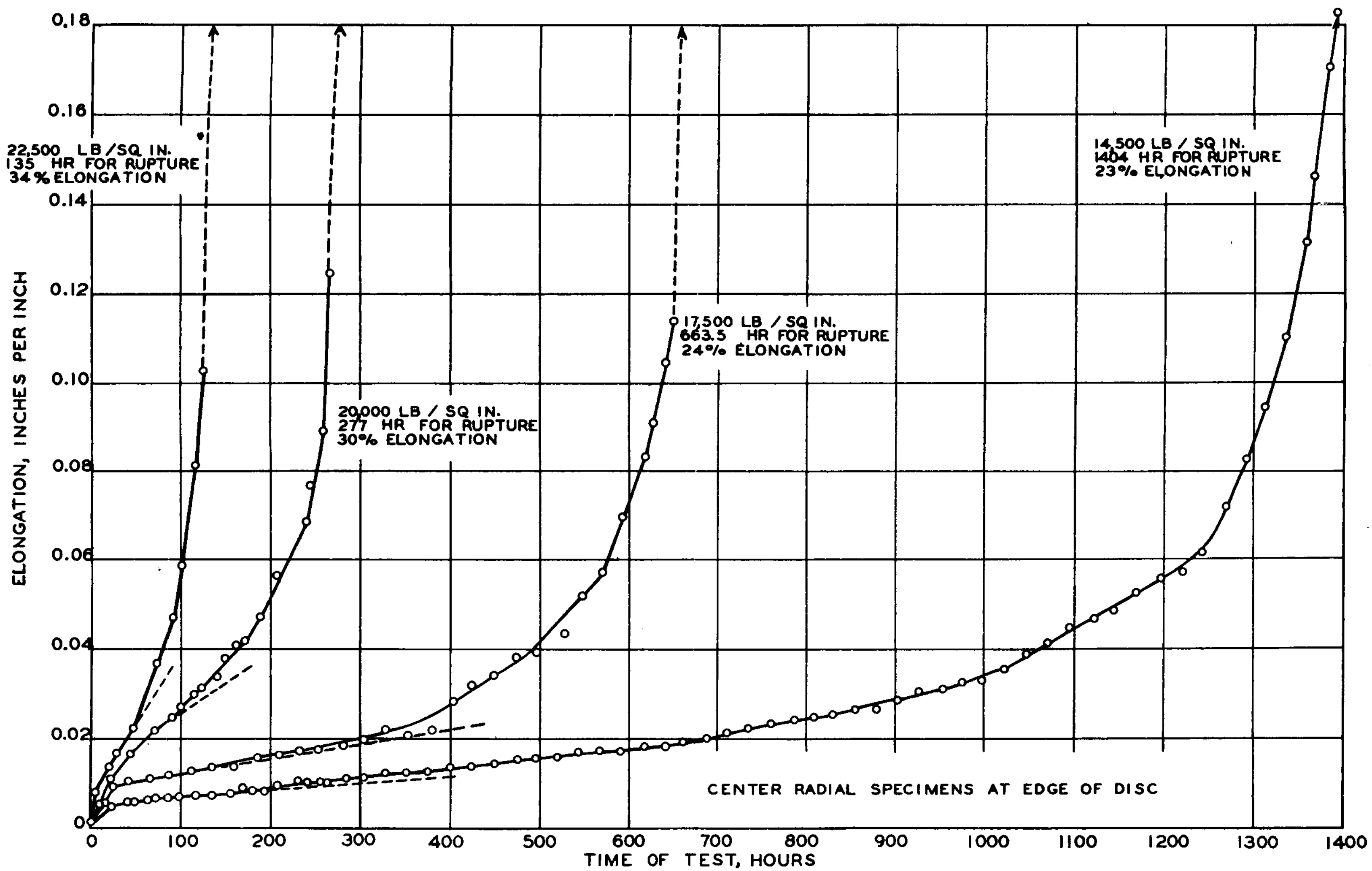


FIGURE 11. - TIME-ELONGATION CURVES FOR RUPTURE TESTS AT 1350° F ON FORGED 19-9 DL ALLOY DISC.

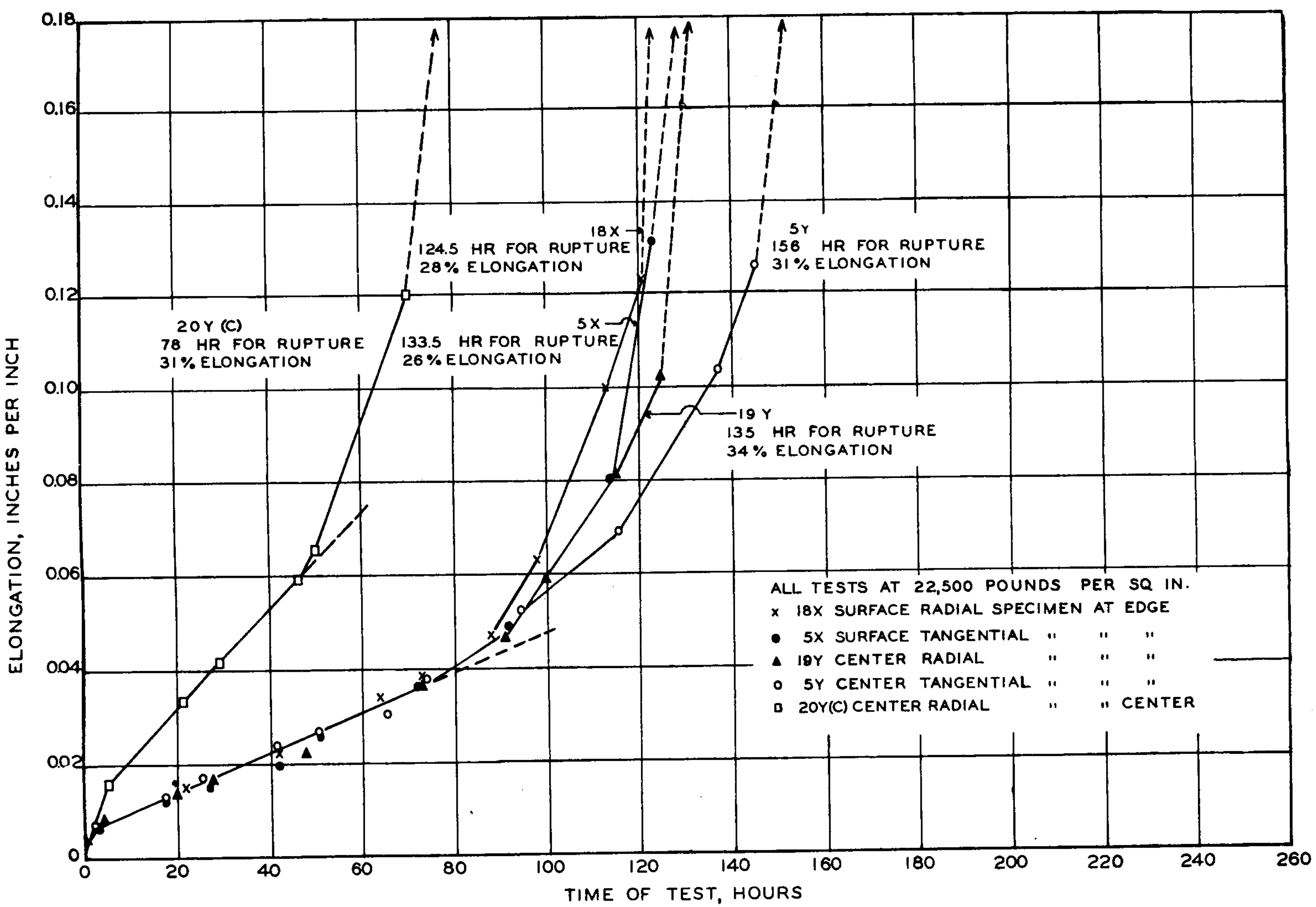


FIGURE 12.- TIME-ELONGATION CURVES FOR RUPTURE TESTS AT 1350° F ON FORGED 19-9 DL ALLOY DISC.

W-74

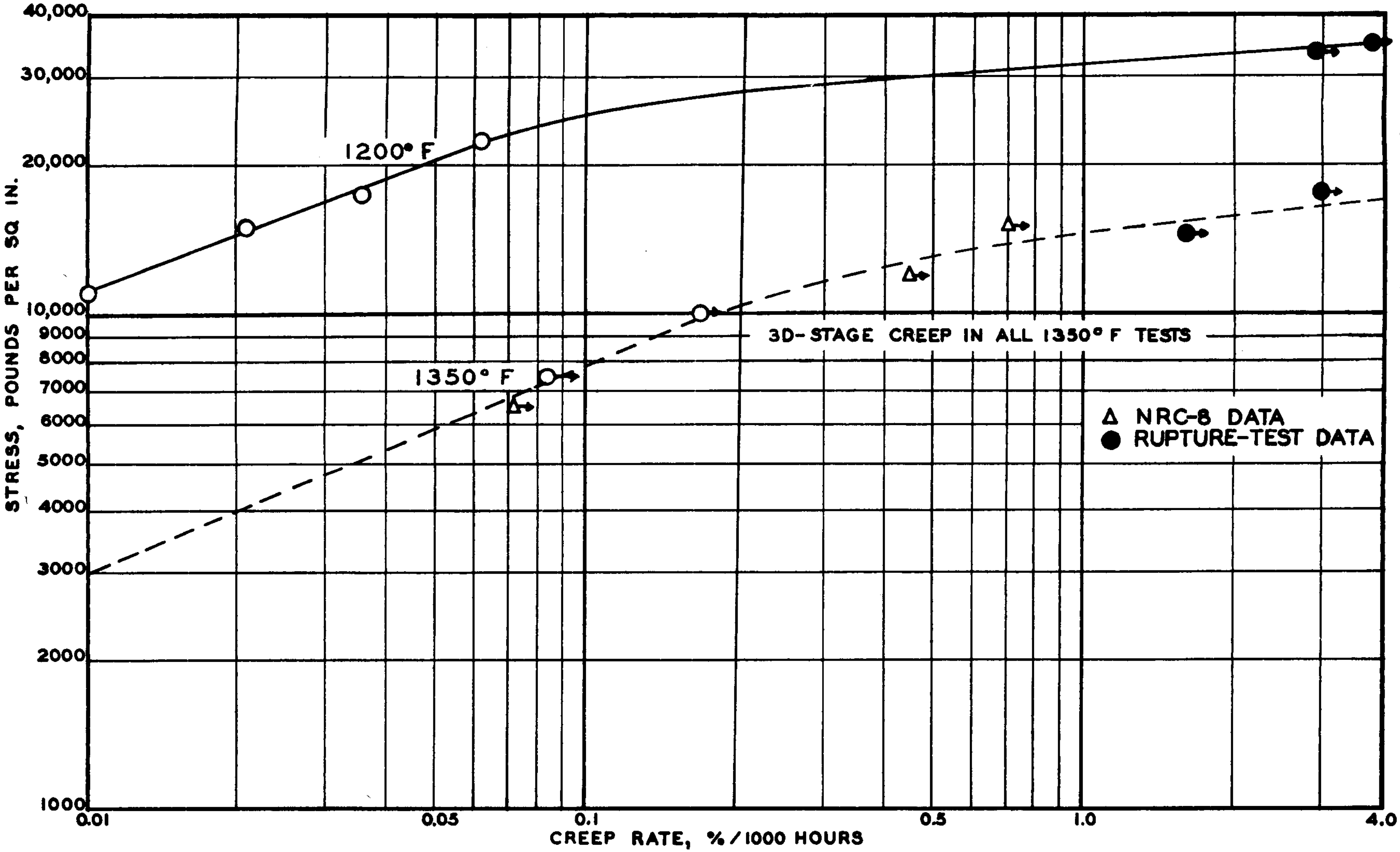
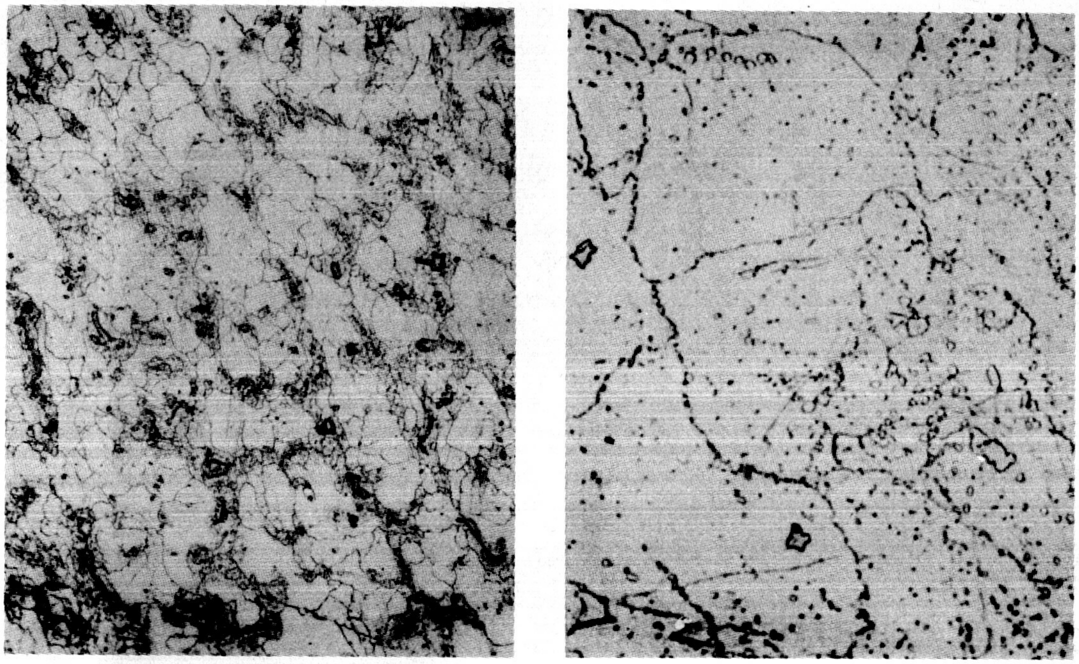


FIGURE 13. - STRESS-CREEP RATE CURVES AT 1200° AND 1350° F FOR 19-9 DL ALLOY FORGED DISC.

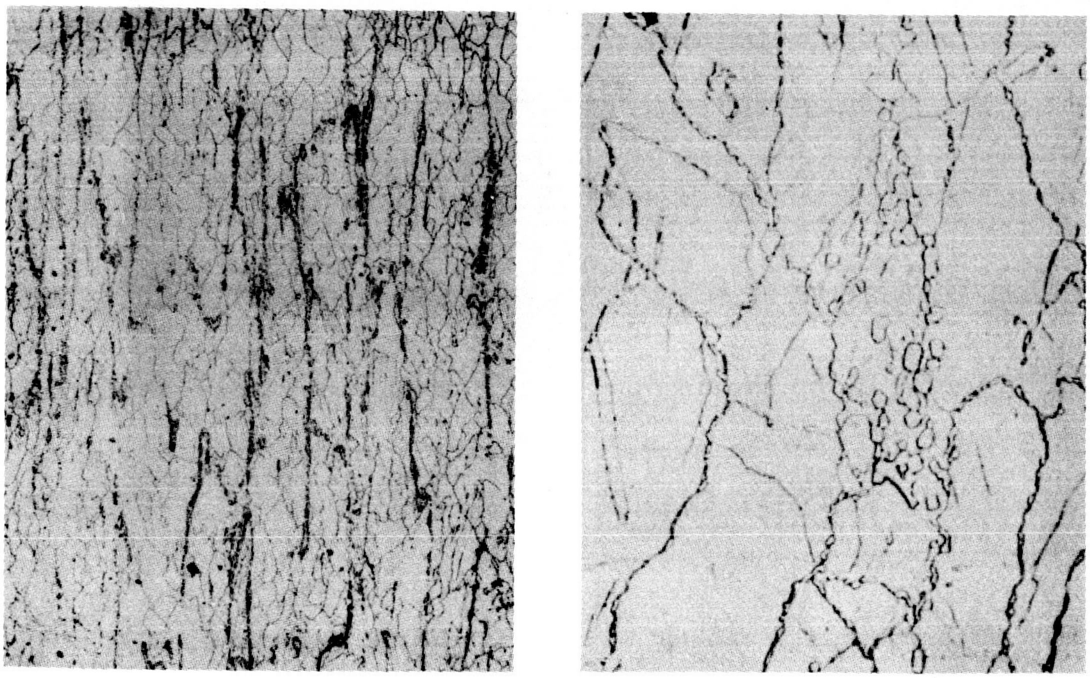
W-74



100X

1000X

(a) Specimen 20X - Radial Section at Rim of Disc



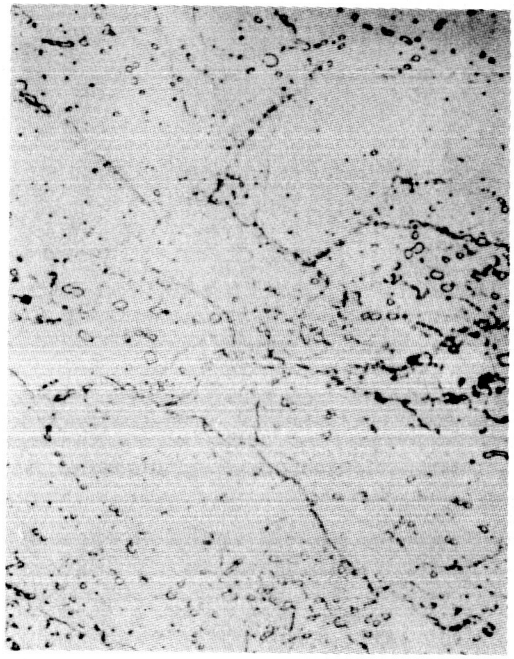
100X

1000X

(b) Specimen 20Y - Radial Section at Center of Disc

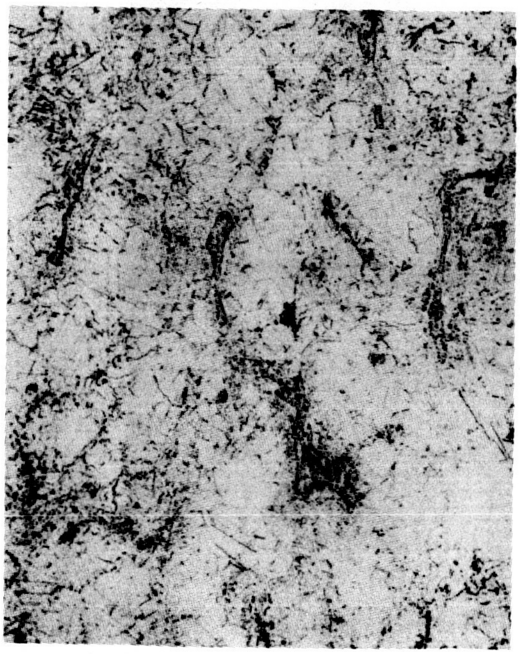
FIGURE 14.- ORIGINAL MICROSTRUCTURE OF DISC.

100X

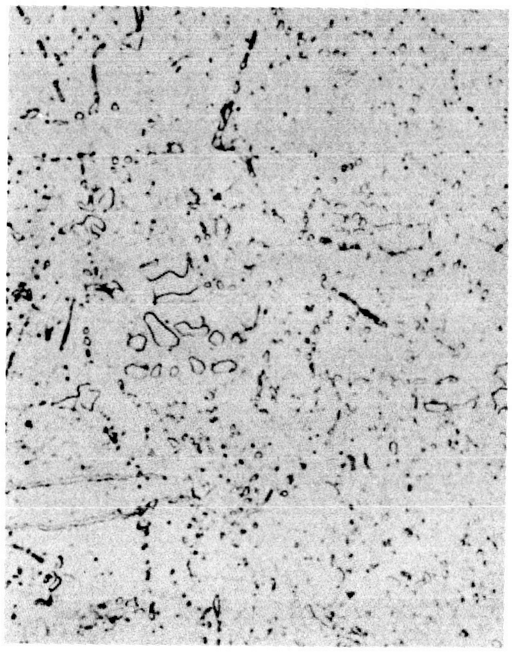


1000X

(a) Specimen DY1 - 2000 Hours at 1200° F under 22,500 lb/sq in.



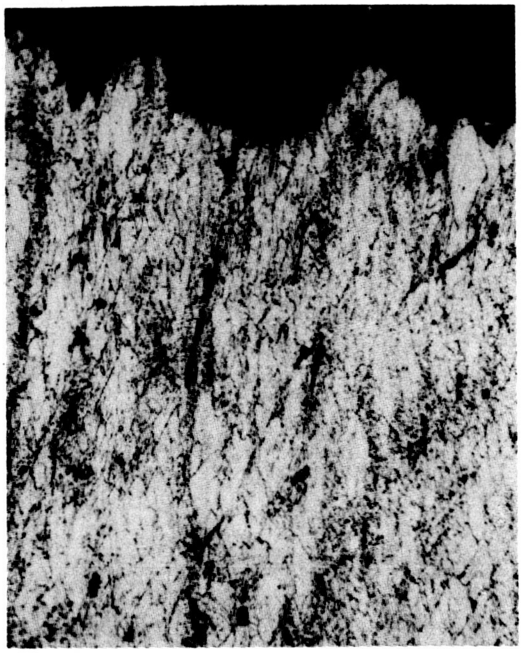
100X



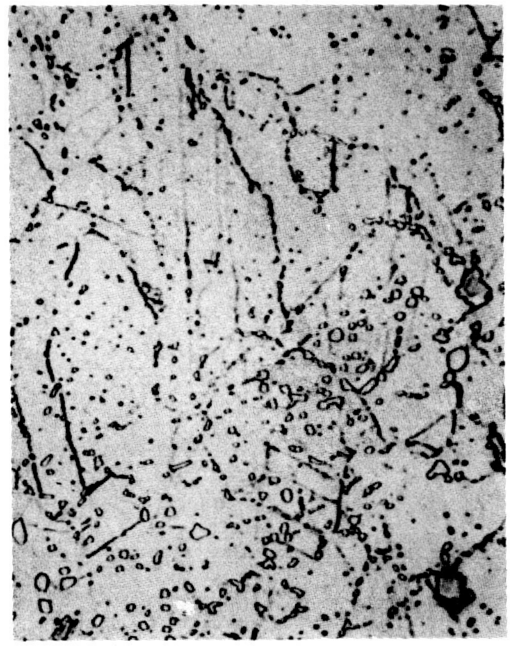
1000X

(b) Specimen EBY1 - 1737 Hours at 1350° F under 10,000 lb/sq in.

FIGURE 15.- MICROSTRUCTURES OF COMPLETED TIME-DEFORMATION TEST SPECIMENS.

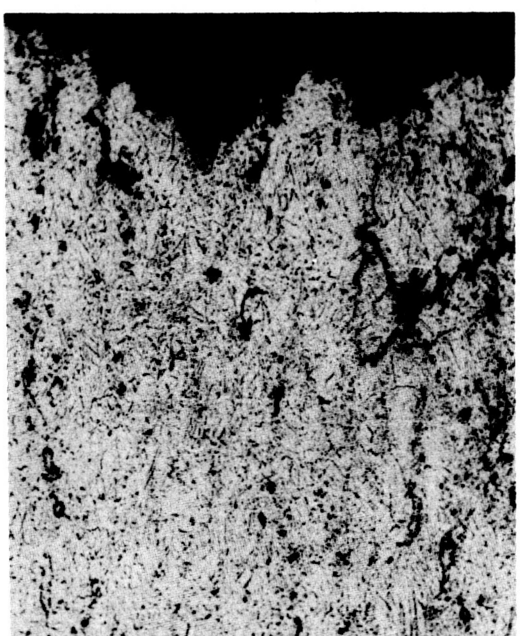


100X



1000X

(a) Specimen 20Y - 1565 Hours for Rupture at 1200° F under 33,500 lb/sq in.



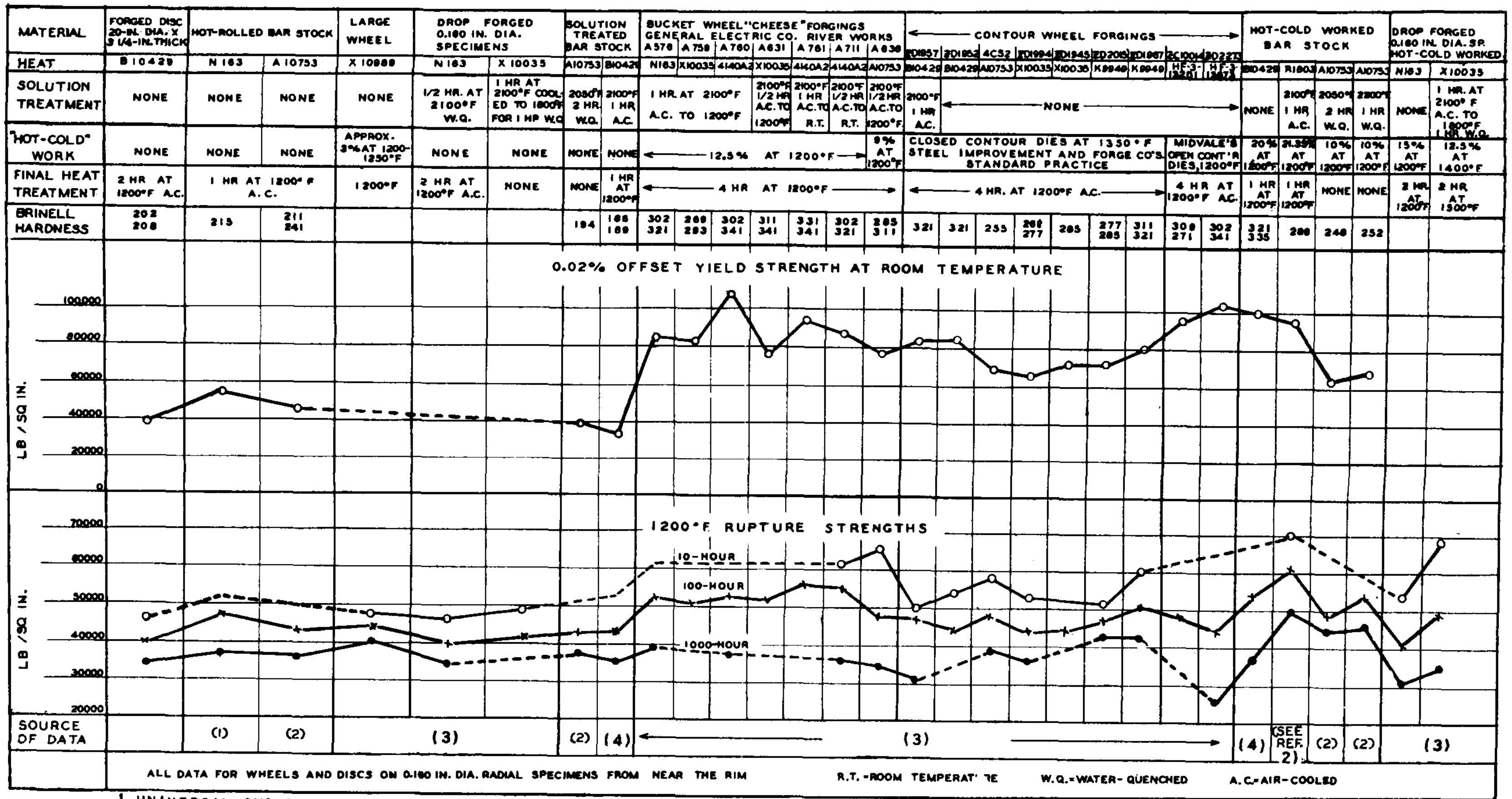
100X

1000X

(b) Specimen 20Y - 1404 Hours for Rupture at 1350° F under 14,500 lb/sq in.

FIGURE 16.- MICROSTRUCTURE OF COMPLETED RUPTURE-TEST SPECIMENS.

W-14



1 UNIVERSAL-CYCLOPS STEEL CORP. DATA.

2 FREEMAN, J.W., REYNOLDS, E.E., WHITE, A.E.: THE EFFECT OF HEAT TREATMENT AND HOT-COLD WORK ON THE PROPERTIES OF FIVE ALLOYS. UNIVERSITY OF MICH., REP. NO. 9. FEB. 26, 1944.

3 GENERAL ELECTRIC COMPANY, RIVER WORKS

4 UNREPORTED DATA FROM INVESTIGATIONS IN PROGRESS.

FIGURE 17. – EFFECT OF PROCESSING PROCEDURE ON THE ROOM-TEMPERATURE YIELD STRENGTH AND 1200° F RUPTURE STRENGTH OF 19-9 DL ALLOY.